MEASUREMENT ARRANGEMENT

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- EP0925482 (A1)

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Cited documents:
- DE2733760 (A1)
- SU911322 (A1)
- FR2626666 (A1)
- DE3425811 (A1)
- SU1363105 (A1)

Abstract of **WO 9716700 (A1)**

A measuring device for determining the thickness of a non-homogenous medium such as the thickness or a road structure. The device includes a radar transmitter Tx and two spaced receivers Rx1, Rx2. Information on the timing of the transmitted signal as well as the signals received by the two receivers is used to calculate the material thickness whilst eliminating signal drift.

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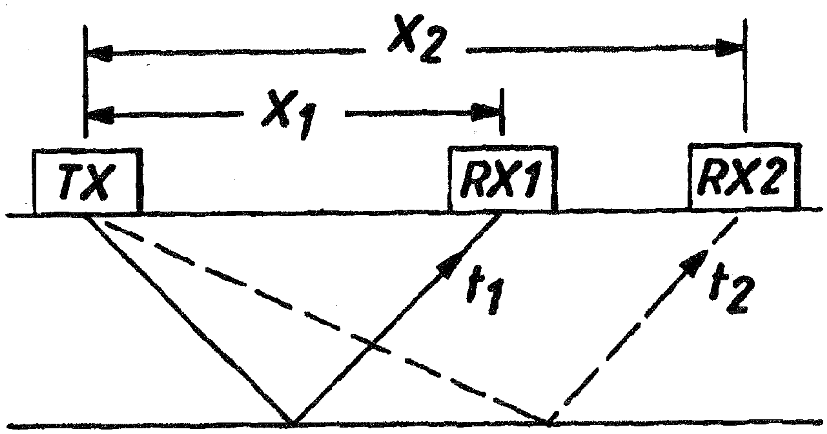

(57) Abstract

A measuring device for determining the thickness of a non-homogenous medium such as the thickness or a road structure. The device includes a radar transmitter Tx and two spaced receivers Rx1, Rx2. Information on the timing of the transmitted signal as well as the signals received by the two receivers is used to calculate the material thickness whilst eliminating signal drift.

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MEASUREMENT ARRANGEMENT

The invention relates to a measurement arrangement typically for road thickness measurement.

Civil engineering materials are often non-homogenous comprising a matrix of two or more products with different particle size and physical properties.

Figure 1 shows part of a typical road structure with a wearing surface layer and a sub base layer of courser material.

Typical of these materials are concrete asphalt and bituminous macadam. When these materials are used as surfacing or cladding for structures such as roads and buildings, it is sometimes necessary to measure the thickness of the surfacing to establish the engineering strength of the structure.

The usual method of measuring the thickness of these materials is to take samples of the material using a coring tool. This can give a very accurate measure if properly used but it suffers from a number of disadvantages. The integrity of the original surface is destroyed by taking a core sample and even if properly repaired it may lead to early deterioration of the surface. Coring of small area structures such as road reinstatements is impractical as the area of the core may be a substantial fraction of the area of the reinstatement. A

core sample provides only a spot measurement which may not be representative of the general condition of the rest of the structure.

Non intrusive measurement techniques have proved difficult due to the non-homogenous matrix of materials employed in such structures.

According to the invention there is provided a device for measuring the thickness of a non-homogenous medium and comprising means for transmitting pulses of electromagnetic energy through the material; first means for receiving a first reflected energy signal; second means spaced from the first means for receiving a second reflected energy signal; and, means for calculating material thickness using information derived from both the first and second reflected signals.

According to a further aspect of the invention there is provided a pulse radar method applicable to the calculation of the thickness of a non-homogenous meduim, comprising passing into the medium from a first location at the outer surface, a pulse of electromagnetic energy and receiving at second and third locations at the surface a reflected pulse and calculating the material thickness using information derived from both received and reflected pulses.

The invention will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 shows a typical road structure arrangement;

Figure 2 shows a radar arrangement forming the basis for measuring the thickness of non-homogenous surfacing materials;

Figure 3 shows the calculation mechanism in more detail;

Figure 4 shows an improved arrangement employing two receivers;

Figure 5 shows the mechanism associated with directly measuring propagation time in the ground;

Figure 6 shows the handling of impulses;

Figure 7 shows a block diagram arrangement for a system capable of providing the Figure 4 configuration;

Figure 8 shows attenuation of signals through their reflection passage; and

Figure 9 shows time varying gain to compensate for such attenuation.

Figure 2 shows the behaviour of a radar signal when passing through a plurality of layers in the road structure and its subsequent receipt.

The operation of the instrument for measuring the thickness of these non-homogenous surfacing materials uses the time of flight of an electromagnetic impulse reflected from the interface between the surfacing material and the underlying material. A microwave antenna Tx acting as a transmitter, placed on the outer surface, injects an impulse of electromagnetic energy into the material. The impulse is reflected from interfaces between layers of material with

different conductivity and permeability, the strength of the reflection being dependent on the differences in electrical parameters. The reflected impulses are detected by a second antenna Rx at the surface which acts as a receiver. The time taken for the signal to make the round trip from the transmitter, through the material and back to the receiver is related to the depth or thickness of the sample as follows:

$$V.t_1 = 2\sqrt{\left(\frac{x_1}{2}\right)^2 + d^2}$$

If the propagation time (t_1) of the signal can be measured and the velocity (v) of the signal in the material is known then since the separation (x_1) of the transmit and receive antennas is also known, then the depth (d) can be calculated as illustrated in Figure 3.

However, with most civil engineering materials the constituents may change significantly between samples and this may result in changes to the velocity of the electromagnetic waves in the material. This in turn affects the estimation of material thickness and large errors can be obtained unless the actual velocity of the material is known. A feature of this invention is to produce a method of measuring material thickness independent of velocity.

In the improved arrangement of Figure 4, this is achieved by using a second receive antenna (RX2), positioned on the surface, in line with the first receive antenna (RX1) but at a greater distance (x2) from the transmitter. If the time (t2) for the impulse from the transmitter to reach the second receiver is measured then the depth of the material can be estimated from the relationship:

$$d = \frac{\sqrt{(t_1 x_2)^2 - (t_2 x_1)^2}}{4(t_2^2 - t_1^2)}$$

The Measurement of Propagation Time

The accuracy and resolution of the measurement technique is dependent, amongst other things, on the frequency content of the electromagnetic impulse that is transmitted into the ground. Typically, measurement of surface layer thicknesses from 50mm to 300mm is required, with an accuracy of better than ±10mm. This accuracy was achieved by generating a very short voltage impulse with an amplitude of 15V and a duration of 350 picoseconds. Most of this signal is fed to the transmit antenna but about 10% is extracted and fed to the receive circuits for use as a timing reference. The transmit antenna converts the voltage impulse into an electromagnetic impulse which radiates into ground. The electromagnetic impulse is partially reflected from material boundaries with different electrical properties. On reaching the surface, the

reflected impulse is detected by the receive antennas, which convert the electromagnetic impulse into a voltage impulse.

In order to measure the propagation time of the impulses (tp) in the ground as illustrated in Figure 5 it is necessary to measure the time difference between the impulse leaving the transmit antenna (tt) and the reflected impulse reaching the receive (tr) antenna. However, this direct measurement is not possible and in practice the time difference is measured between the generated voltage impulse (tg) and the detected voltage impulse (td). The time difference (td) is longer than the propagation time in the ground (tr)-(tt) due to time delays in the cables and couplers feeding the antennas. Thus, unless corrected, the measurement of time difference of the generated and detected voltage impulses will give a systematic error which will overestimate the depth. This problem has been overcome by carrying out a set of time measurements on a material with a range of thicknesses and extrapolating the results to a material thickness of zero. At this point (tt) = (tr) and the time difference measured by the system (to) is caused only by the delays in the cables and components. For a system where the time delays in the cables and connectors are fixed, then the propagation time in the material can be calculated by subtracting (to) from the total measured time:

$$tp = (td-tg)-to$$

Electronic Time Measurement

The velocity of electromagnetic radiation in solid materials is very fast, for instance in bituminous materials, the velocity is in the region of 100mm/ns. Because of the accuracy of measurement required in this application, of 10mm or better, then time differences of less than 0.1ns (100ps) must be measured. Electronic circuits for the direct measurement of these very short impulses are complex and very expensive and therefore an indirect method is used to measure the time differences. This technique is called downsampling in which the voltage impulse at the receiver is digitally sampled and stored and then reconstructed over a much longer timescale. The effect is to convert a pulse with a duration of 350ps to an impulse of 0.35ms duration.

The short duration (350ps) impulses are generated and passed into the ground at a rate of 160khz (i.e. 160,000 impulses per second). As each of the reflected impulses are detected by the receive electronics, a single digital sample is taken from a point on the received waveform as illustrated in Figure 6. For the first impulse received the sample will be taken from the start of the waveform. For each subsequent received impulse, the timing module progressively increments the point on the waveform at which the sample is taken by 6.1ps. Therefore over a sequence of 4096 impulses (i.e. over a period of 4096/160000 seconds = 0.025s = 25ms) the timing module increments the sample time by a total of 4096 x 6.1ps = 25,000ps = 25ns). At the end of this sequence, which has taken 25ms the sampler has effectively sampled a time window

of 25ns for the received signal waveform. This stretching of the time window by a factor of 1000,000 allows more conventional electronic circuitry to be used to amplify and filter the waveforms prior to digital conversion for processing, display and storage.

Clearly the accuracy of the system depends on measurement of very small time differences between the transmit channel and the receive channel which can be much smaller than relative timing drift between channels caused by temperature and component drift.

In order to substantially eliminate the effects of this drift, our arrangement employs a reference pulse from the transmit signal into the receive channel.

This reference pulse is superimposed on the received waveform. Any change in the timing of the control circuitry which changes the position of the sample of the received waveform will equally affect the position of the reference pulse. Taking timing measurements on the received waveform with respect to the reference pulse rather than to the start of the waveform thus eliminates differential timing drift in all signal paths common to both signals. The only components not included are the antennas and the associated cables. The drift associated with these will be small and predictable, typically substantially below 10 picoseconds.

Figure 7 shows an embodiment suitable for operating in this manner. Couplers 10, 11 and 12 are provided with an associated splitter 13. Received signals are passed to pre-amplifiers 14 and 15 and thence to samplers 16 and 17 acting as sample and hold devices. Filtering and amplification in block 18 provides the output signals for channels A and B.

The control logic block 20 controls system operation including timing module 22.

The control logic module generates the overall timing for the system, generating a transmit rate clock to trigger the sampling timing circuitry and sweep to control the receiver timebase range. It also provides an overall framing signal to define in time the start and finish of a sampling sweep, to ensure correct synchronisation of the data acquisition system.

The gain control logic block 21 controls the level of amplification as required for the time varying gain (described below in relation to Figure 8). The conditioned analogue signals from channels A and B are digitised in analogue to digital converters 25, 26 and the information taken at the appropriate time by acquisition and computation block 28 which includes a microprocessor. The computed thickness value is made available to display 29 which can provide representation in graphical form for the reflected signals and also a direct depth value in numerical form.

Transmission pulses pass from the transmitter integrated circuit 23 via coupler 12 to the transmit antenna. Splitter 13 provides the reference pulse to the receiving circuitry for timing purposes and appears in the received channel waveform between the start of sweep and the start of the received waveform.

Time Varying Gain

Impulses which are reflected from deeper layers in the ground appear later in the waveform of the receiver channel because of the greater distance travelled in the material. These signals are usually more attenuated as shown in Figure 8 because of the greater distance travelled and measurement of these smaller amplitude signals is more difficult. Compensating gain is applied within the receiver to offset this effect and thus reduce the dynamic range of the received signal. This compensating gain is applied in two stages, before and after the down-sampler. Using Time Varying Gain, it is possible to introduce a greater gain for signals later in the trace than those at the start of the trace as shown in Figure 9. The degree of additional gain is selectable in steps of 10db from 0db to 20db. This is achieved by means of a function ROM and digital-to-analogue convertor synchronised to the sweep circuitry.

Calculation of Material Thickness

The downsampled waveforms signals are converted to digital signals using the analogue-to-digital convertor. The digitised waveforms are then passed to the microprocessor within block 28 which used conventional processing techniques to automatically locate the peaks in the waveforms and measure time differences. The microprocessor then uses the measured time differences to calculate the material thickness and the value of the thickness is displayed on a numerical display for the operator. New waveforms are received from the downsampler every 25ms so that a new estimate of material thickness can be made and displayed every 25ms. If the antenna array is scanned over the area of interest, then a reading of the thickness every 25ms will provide a detailed profile of the material thickness.

Hence a sweep comprises a sequence of transmit pulses for each of which the samplers are triggered to sample a point on the received waveform. The transmitter and receiver operate at a repetition frequency of approximately 160khz, constructing a waveform every 25ms from a sequence of 4096 samples. For each of the transmit pulses the timing module alters the point in time at which the samplers are triggered, sampling a different point on the waveform. This timing increment is such as to alter the transmit to receive timing by a total of 25ns from the start to the end of the trace, providing a corresponding time window for the receiver. The sequentially sampled waveform from the sampler is amplified and passed through an

anti-aliasing filter before being digitised as described above.

The data acquisition circuitry cannot operate at the trigger rate of the sampling system. Therefore, during the period of 25ms comprising a time trace, the data acquisition converter operates at a reduced conversion rate, digitising the received waveform into 512 points. Thus for each digitised value the RF subsystem has received 8 sample values. The effect of the anti-aliasing filter is to average these 8 values, producing an improvement in received signal-to-noise ratio of approximately 8dB. An additional benefit of this reduced conversion rate is that the output from the receiver falls within the audio band. This enables the use of low cost high performance devices and software normally used for the digital audio market.

Although the arrangements have been described generally in relation to road thickness measurement, it would be applicable to other non-homogenous civil engineering media.

CLAIMS

1. A device for measuring the thickness of a non-homogenous medium and comprising means for transmitting pulses of electromagnetic energy through the material; first means for receiving a first reflected energy signal; second means spaced from the first means for receiving a second reflected energy signal; and means for calculating material thickness using information derived from both the first and second reflected signals.

2. A device as claimed in claim 1 wherein the calculating means includes means for determining thickness independent of signal velocity.

3. A device as claimed in claim 2, wherein the means are configured to determine thickness independent of signal velocity changes due to the constitution of the medium.

4. A device as claimed in claim 1, 2 or 3, wherein reference information means are provided to utilise information derived from the signal to be transmitted to compensate for signal drift.

5. A device as claimed in any one of claims 1 to 4 wherein time manipulation means are provided to effectively expand the short duration time window to allow relatively slow computation circuitry to be employed.

6. A device as claimed in any one of claims 1 to 5 including means for compensation for pulse attenuation dependent on transmission path length.

7. A device as claimed in claim 6 wherein the compensation means includes means for providing time variable gain.

8. A device as claimed in any preceding claim wherein means are provided for scanning an area of the medium to determine thickness at a number of locations within the area.

9. A device as claimed in any preceding claim including sampling means and means for computing a digital signal derived from the sample information to determine distance dependent on the passage of the electromagnetic impulse through the medium and display means for displaying the result.

10. A device as claimed in claim 9 wherein the transmitter is configured to provide an electromagnetic impulse of very short duration not exceeding several hundred picoseconds.

11. A device as claimed in any preceding claim wherein the transmitter, receivers and calculating means are configured to measure a relatively shallow non-homogenous medium such as in a road or building structure.

12. A device as claimed in any preceding claim wherein means are provided for sampling, storing and reconstructing impulses to allow time differences in the region of 100 picoseconds to be determined.

13. A pulse radar method applicable to the calculation of thickness of a non-homogenous medium, comprising passing into the medium from a first location at the surface pulse of electromagnetic energy and receiving at second and third locations at the surface the reflected pulse and calculating the material thickness using information derived from both received and reflected pulses.

14. A method as claimed in claim 13 wherein the pulse of electromagnetic energy is generated to be very short duration not exceeding several hundred picoseconds.

15. A method as claimed in claim 13 or 14 including the steps of sampling, storing and reconstructing the received information to allow relatively shallow thickness to be determined.

16. A device for measuring the thickness of a non-homogenous medium substantially as described herein with reference to Figures 4 to 9 of the accompanying drawings.

17. A pulse radar method applicable to the calculation of the thickness of a non-homogenous medium substantially as described herein.

FIG.1.

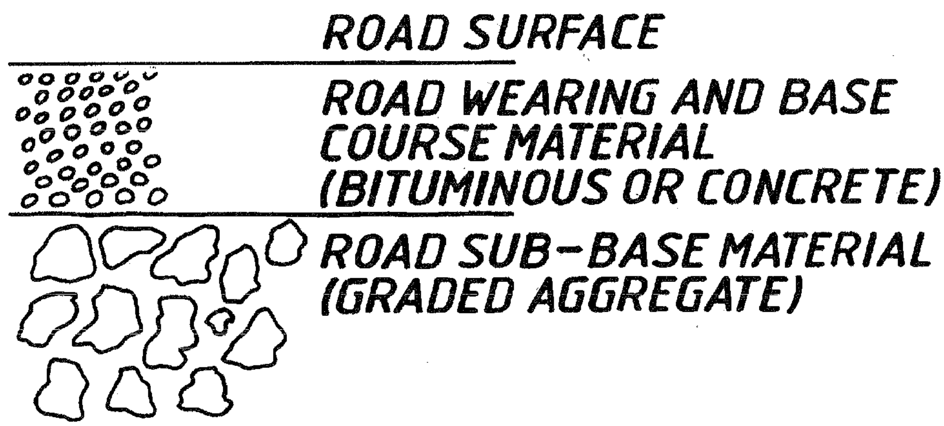

ROAD SURFACE
ROAD WEARING AND BASE COURSE MATERIAL (BITUMINOUS OR CONCRETE)
ROAD SUB-BASE MATERIAL (GRADED AGGREGATE)

FIG.2.

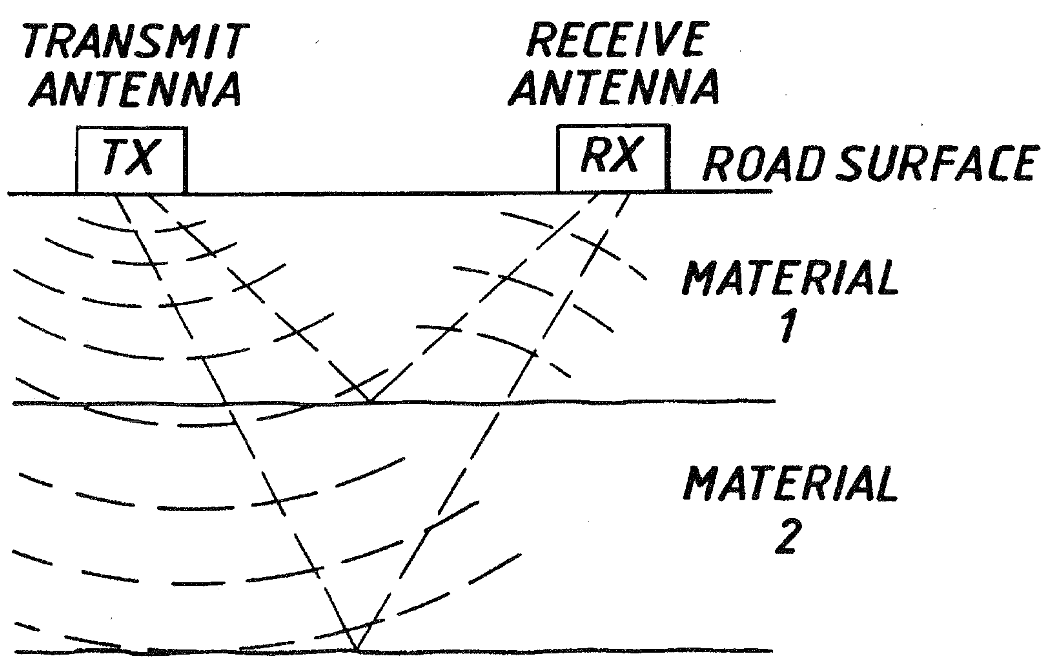

TRANSMIT ANTENNA
RECEIVE ANTENNA
TX
RX
ROAD SURFACE
MATERIAL 1
MATERIAL 2

FIG. 3.

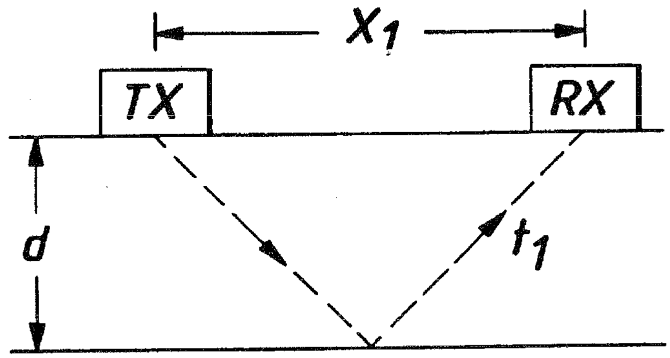
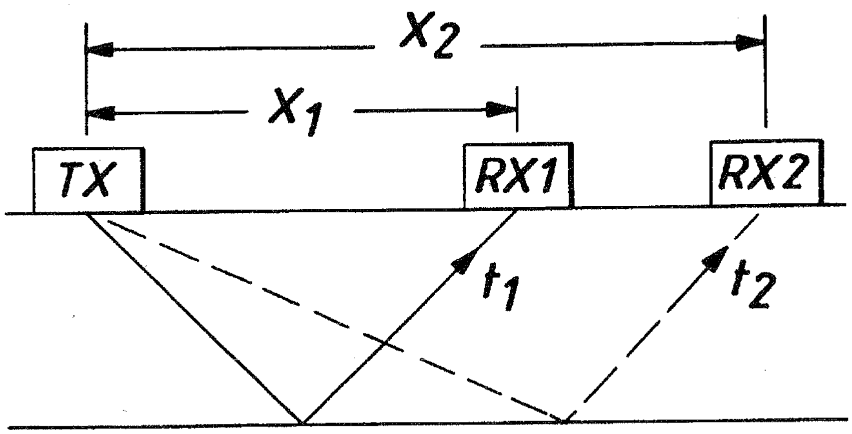


FIG. 4.



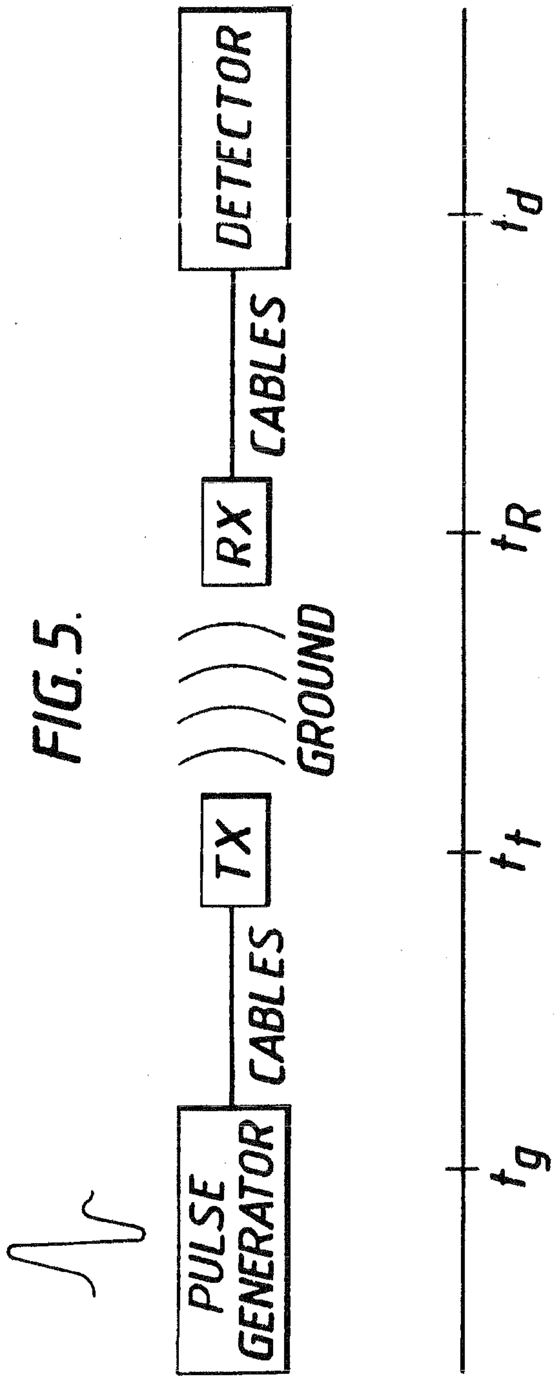

PULSE GENERATOR
CABLES
TX
GROUND
RX
CABLES
DETECTOR
t_g
t_t
t_R
t_d

FIG.5.

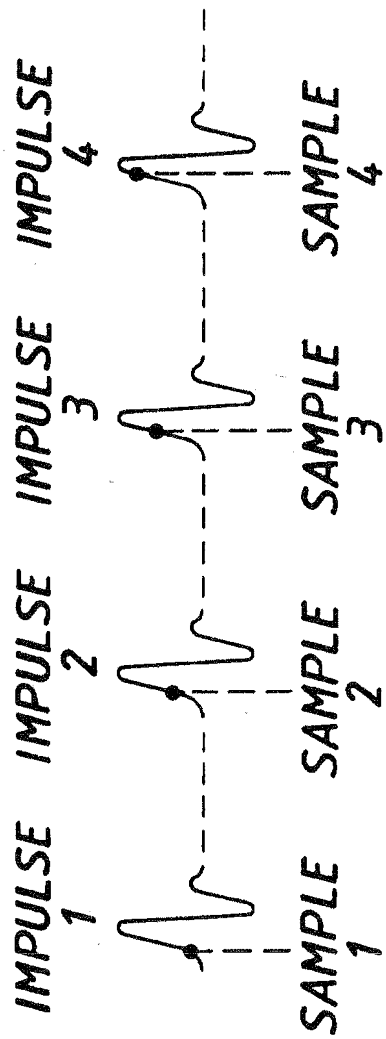
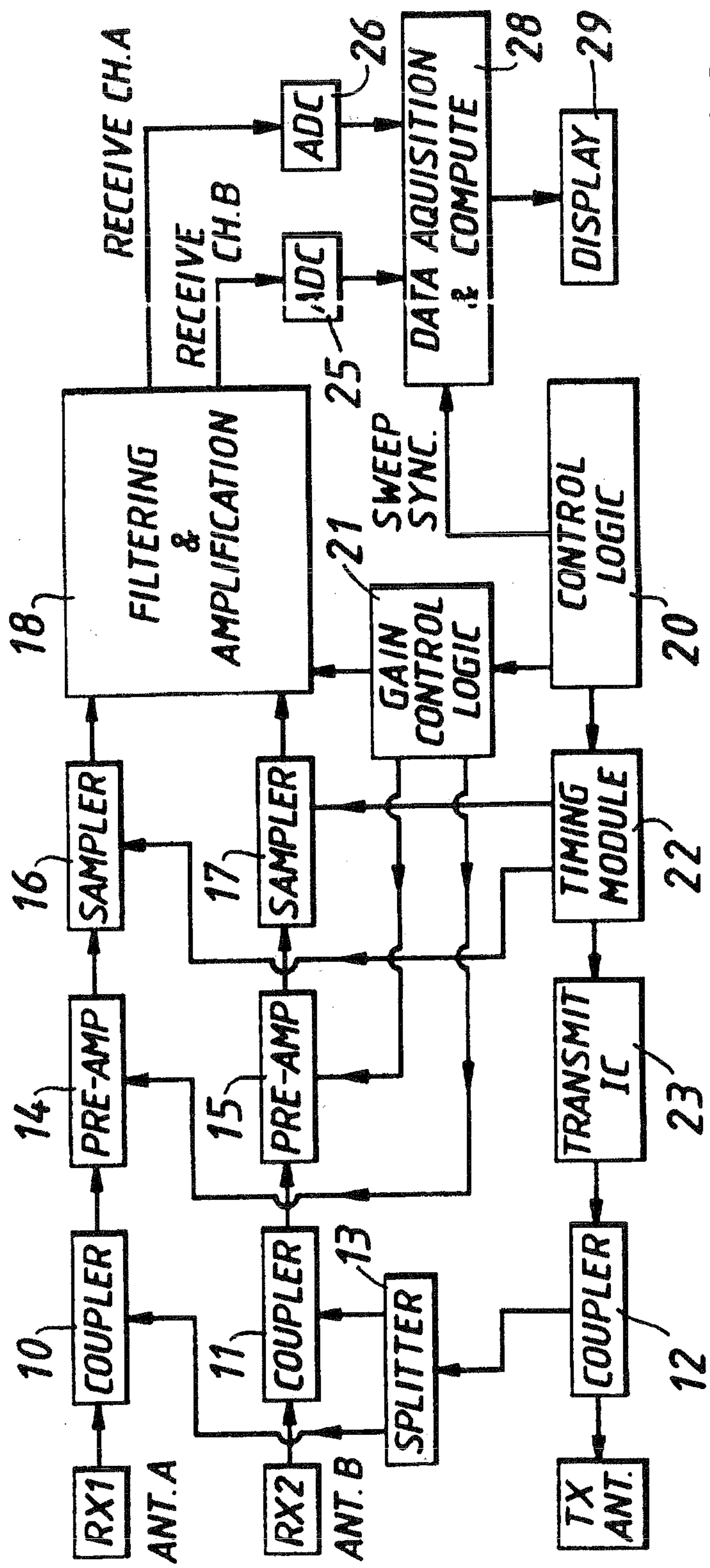

IMPULSE 1
IMPULSE 2
IMPULSE 3
IMPULSE 4
SAMPLE 1
SAMPLE 2
SAMPLE 3
SAMPLE 4

FIG.6.

FIG. 7.



SYSTEM FUNCTIONAL DIAGRAM

FIG. 8.

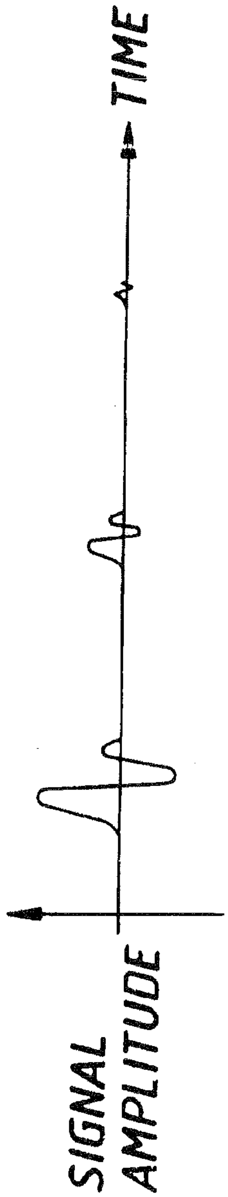
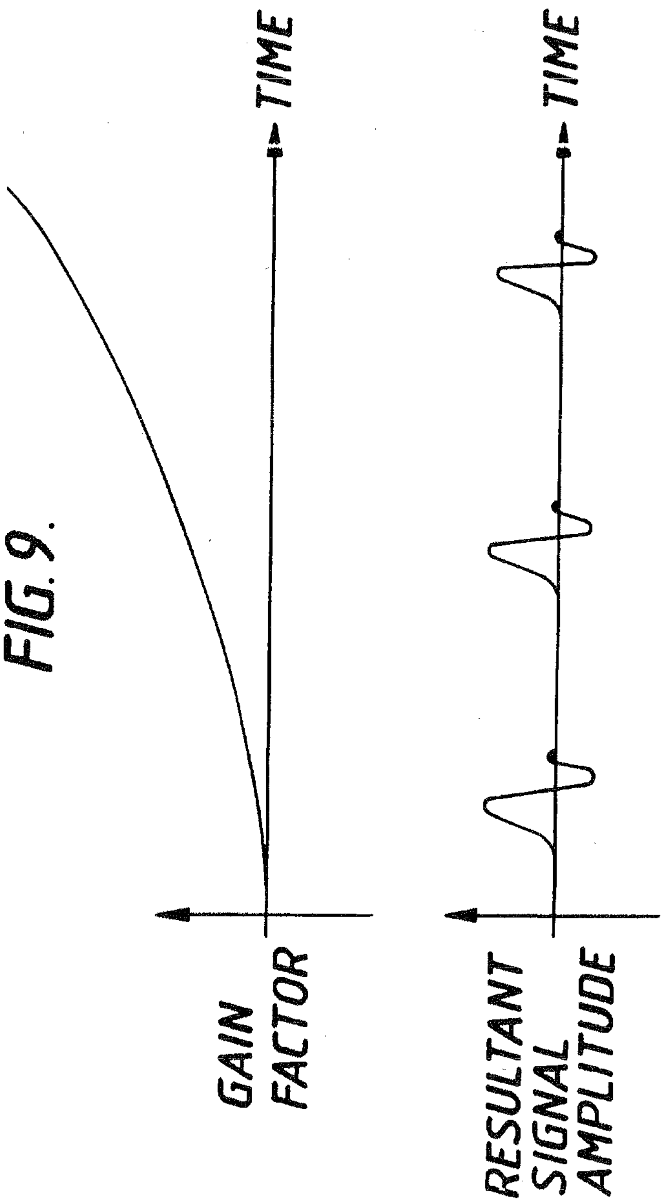

TIME
SIGNAL AMPLITUDE

FIG. 9.


TIME
GAIN FACTOR
TIME
RESULTANT SIGNAL AMPLITUDE

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 96/02692

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01B15/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DE 27 33 760 A (CASPERS FRIEDHELM DIPL ING) 15 February 1979 see page 5, paragraph 4 - page 8	1
A		5,9,11, 15

Y	SU 911 322 A (KARAMYSHEV MURAD A;KONNOV VALERIJ N; KHAJRETDINOV VIKTOR R) 7 March 1982 see abstract; figures	1
A		2,3

A	FR 2 626 666 A (FRANCE ETAT PONTS CHAUSSEES) 4 August 1989 see page 6, line 20 - page 7, line 32; figures	1,5,9,13

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[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 February 1997	20.03.97

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/02692

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 34 25 811 A (FRAUNHOFER GES FORSCHUNG) 14 March 1985 see abstract; figures ---	1-3
A	SU 1 363 105 A (RIGA CIVIL AVIAT ENGGS) 30 December 1987 see abstract; figures -----	1

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 96/02692

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 2733760 A	15-02-79	NONE	
SU 911322 A	07-03-82	NONE	
FR 2626666 A	04-08-89	NONE	
DE 3425811 A	14-03-85	NONE	
SU 1363105 A	30-12-87	NONE	